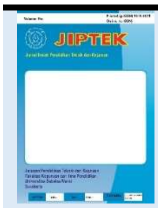

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Development of Pyrolysis Learning Media in New and Renewable Energy Courses

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ABSTRACT

This study aims to develop a pyrolysis learning medium in the form of a practicum apparatus and an interactive e-module to support learning in the Renewable Energy course in the Mechanical Engineering Education Program, Faculty of Teacher Training and Education, Universitas Sebelas Maret. This research is motivated by the limited availability of practical learning media, which has caused pyrolysis learning to be predominantly theoretical. The research employed a Research and Development (R&D) approach using the ADDIE development model. Media validation was conducted by subject-matter experts and media experts, while user testing involved 13 students. Data were collected using expert validation questionnaires, pretest–posttest instruments, user trial questionnaires, and interviews. The validation results indicated a very high level of feasibility, with scores of 95% from subject-matter experts and 81.76% from media experts, while user testing showed a feasibility level of 82.4%. The developed learning media helped students understand the pyrolysis process in a visual and applicative manner and increased their engagement and conceptual understanding. Therefore, this study contributes to the enhancement of Renewable Energy learning through the provision of contextual pyrolysis practicum media and has important implications for improving the quality of technical and vocational education by integrating practice-based and technology-enhanced learning.

Keywords: *learning media, pyrolysis, renewable energy, ADDIE*

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INTRODUCTION

Quality education is a crucial foundation for improving the skills and knowledge of the younger generation, enabling them to face global challenges(Costan et al., 2021; González-pérez & Ramírez-montoya, 2022). In higher education, improving the quality of learning is inextricably linked to the availability of adequate facilities and infrastructure. Law of the Republic of Indonesia Number 20 of 2003 concerning the National Education System affirms the obligation of educational institutions to provide learning facilities and infrastructure. The availability of relevant learning facilities, such as classrooms, laboratories, and learning resources, is a crucial factor in creating a conducive learning environment (Hafiluddin & Wahyudin, 2023).

In the context of vocational education, learning resources and media play a more crucial role because learning requires mastery of practical skills relevant to the world of work. Applicable learning media are needed to bridge the gap between theory and practice (Ni'mah et al., 2024). This is in line with the Cone of Experience theory put forward by Edgar Dale, which emphasizes that direct learning experiences are more effective than abstract learning(Dewi et al., 2024).

Learning media serves as a means of knowledge transfer that supports the creation of an effective learning process(Staneviciene & Žekienė, 2025; Zamiri & Esmaeili, 2024). Media designed interactively and contextually can help students understand concepts more deeply and increase engagement in the learning process (Kurniawan et al., 2021). In addition, the use of learning media also plays a role in encouraging active and independent learning, especially in practical courses (Busthomi, 2023). Therefore, the development of learning media that is appropriate to the characteristics of the teaching materials and students is an important aspect in improving the quality of learning in engineering education.

The selection of appropriate learning media must be tailored to the type of teaching material and the characteristics of the students. The right media not only accelerates conceptual understanding but can also increase student motivation and confidence in dealing with complex material (Shabrina et al., 2025). One of the main challenges in engineering education is conveying technical concepts clearly and practically. Therefore, developing learning media that integrates simulations, practical tools, and interactive modules is an important solution for bridging theory and practice.

In the context of the New and Renewable Energy (NRE) course in the Mechanical Engineering Education Study Program, Faculty of Teacher Training and Education, Universitas Sebelas Maret, pyrolysis is one of the core materials that requires a practical approach. Pyrolysis is the process of converting plastic waste into oil, which has a high calorific value and has the potential to be used as an alternative fuel (Gunandi et al., 2020). By heating organic materials in oxygen-free conditions, this process produces products such as bio-oil, biogas, and bio-char, which can be used as energy sources(Zulkafli et al., 2023). Considering the urgency of dealing with plastic waste as well as renewable energy solutions, a good understanding of the pyrolysis process is important for engineering students.

Indonesia itself has enormous potential for renewable energy development. Various energy sources, such as solar, wind, biomass, hydro, and geothermal, are widely distributed across various regions (De et al., 2023). Biomass, including plastic, can be utilized as a renewable energy source through the pyrolysis process. However, learning about renewable energy, particularly pyrolysis, in educational institutions remains limited to theory. The lack of practical facilities and pyrolysis equipment is a major obstacle to delivering the material in a holistic and applicable manner (Apriliyanti & Rizki, 2023). In fact, in engineering education, the ability to apply theory in real practice is very important to produce competent and work-ready graduates.

Students who only receive theoretical pyrolysis instruction tend to have a low level of understanding. This is exacerbated by the lack of visual media or tools that can directly visualize the pyrolysis process (Kanti et al., 2022). Therefore, a learning medium is needed that can bridge these limitations. The development of a simple pyrolysis tool and interactive learning e-modules is an approach that can provide a more contextual and meaningful learning experience.

Interactive e-modules designed according to pedagogical and technological principles have great potential to support independent learning. They enable students to learn anywhere and anytime, and present content in various formats, such as text, images, videos, and simulations, to strengthen conceptual understanding (Sipayung & Purba, 2024). In this case, the developed e-module not only presents theoretical pyrolysis material but also guides students in understanding experimental procedures, identifying tools and materials, and evaluating the results of the pyrolysis process. Thus, the e-module complements the developed pyrolysis practical tools.

Previous studies have shown that the use of learning media designed based on the ADDIE model (Analysis, Design, Development, Implementation, Evaluation) can significantly increase learning effectiveness(Syahid et al., 2024). This model provides a systematic approach to developing learning media, from needs analysis and design to product development, field implementation, and effectiveness evaluation. The use of the ADDIE model in the development of pyrolysis tools and learning e-modules provides a measurable framework and is oriented towards the quality of the results.

Pyrolysis is not only a technical solution but also has educational value in teaching students the concepts of renewable energy and sustainability. This process involves understanding thermodynamics, basic chemistry, equipment engineering, and environmental impact analysis (Das & Ghosh, 2022). Therefore, the learning media developed must be able to present these multidisciplinary aspects in an integrative manner. With a simple pyrolysis tool and accompanying e-module, students not only understand the technical process but can also apply that knowledge in broader contexts such as waste management and energy conservation.

Pyrolysis learning in the New and Renewable Energy course at Universitas Sebelas Maret has so far been dominated by a theoretical approach and has not been supported by adequate practical media, resulting in students' limited and less applicable understanding of the pyrolysis process. This condition reflects a gap between the demands of practice-based learning in engineering education and the availability of contextually relevant instructional media. Although previous studies have explored the development of e-modules and practicum tools in engineering education more broadly, empirical development studies that integrate a physical pyrolysis apparatus with an interactive e-module — specifically validated and tested for feasibility in a mechanical engineering education context — remain limited.

Therefore, this study addresses this gap by developing pyrolysis learning media consisting of a simple practicum apparatus and an interactive flipbook-based e-module using the ADDIE model. The objectives of this study are: **(1)** to develop AR-based pyrolysis learning media in the form of a practicum apparatus and an interactive e-module for the New and Renewable Energy course; **(2)** to assess the content and media feasibility of the developed media based on expert validation; and **(3)** to examine student and teacher responses as initial evidence of user feasibility and learning effectiveness. This study is expected to contribute to the development of practice-based instructional media in vocational and technical engineering education by demonstrating how the integration of physical practicum tools and digital learning modules can bridge the gap between abstract pyrolysis concepts and hands-on workshop experience

RESEARCH METHODS

The type of research used in this study is Research and Development (RnD) with the ADDIE development model, which consists of five stages: Analyze, Design, Development, Implementation, and Evaluation (Gall et al., 2007). This model was chosen because it provides a systematic flow in developing valid and applicable educational products. The ADDIE research flow can be seen in Figure 1.

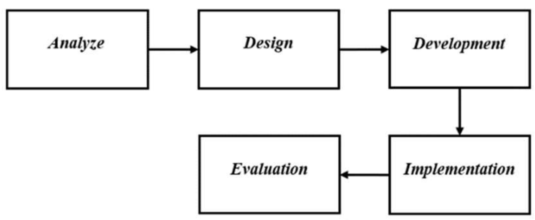

Figure 1. ADDIE Research Flow

This research was conducted at the Mechanical Engineering Education Laboratory, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Surakarta, from August 2024 to April 2025. This location was chosen because it is the location for student practice in engineering learning and has adequate facilities for tool development and trial implementation.

The research targets and subjects consist of two groups: (1) Media validation subjects, namely two lecturers who are material experts in the field of New and Renewable Energy, as well as two lecturers who are experts in learning media, and (2) 13 students of the Mechanical Engineering Education Study Program, FKIP UNS, class of 2023 who have never taken a New and Renewable Energy course as user trial subjects. The determination of the number of subjects is based on the provisions of small group trials (Creswell, 2013). So the trials in this study were focused on small groups as an initial stage of development before testing was carried out on a wider scale.

The research procedure follows the ADDIE stages, namely:

1. Analysis: Conduct a preliminary study of the pyrolysis learning conditions in the PTM FKIP UNS study program and identify learning media needs.
2. Design: Design a pyrolysis tool and a flipbook-based e-module based on learning outcomes.
3. Development: Create a prototype of the tool and e-module and validate it by subject matter and media experts.

4. Implementation: Test the product on students through hands-on practice and use of the e-module.
5. Evaluation: Evaluation is based on validation results, pretest-posttest, user questionnaires, and in-depth interviews.

Research instruments include:

1. Expert validation questionnaire, to assess the appropriateness of content, language, presentation, graphics (material), and technical feasibility and design (media).
2. User trial questionnaire, to evaluate the quality, effectiveness, and satisfaction with media use.
3. Pretest and posttest questions, to measure students' understanding of pyrolysis.
4. Interview guide, to explore students' experiences and perceptions regarding media use.

The data collection techniques used are:

1. Tests (pretest and posttest)
2. Questionnaires (using a 1-5 Likert scale for experts and users)
3. Semi-structured interviews (with three students, selected based on their extreme high, medium, and low scores in the questionnaire results).

Data analysis techniques were conducted quantitatively and qualitatively. Quantitative data were analyzed using percentage feasibility scores and gain tests to determine improvements in understanding (Hake, 1998). Qualitative data were analyzed using the analysis model proposed by Miles & Huberman (1994) for interviews, to strengthen quantitative results and understand the user context more deeply.

RESEARCH RESULTS AND DISCUSSION

This research was conducted using the ADDIE development model, which consists of the stages of Analysis, Design, Development, Implementation, and Evaluation. Each stage contributes to the creation of effective, valid, and applicable pyrolysis learning media to support the learning process in the New and Renewable Energy course. The research results are systematically described below:

1. Analyze

In this initial stage, researchers identified needs through discussions with lecturers and students who had taken the New and Renewable Energy course. The analysis revealed that pyrolysis learning had been largely theoretical, with no practical learning media available to clarify the concept of converting plastic waste into fuel oil. This situation resulted in students' poor understanding of the pyrolysis process. This finding is in line with the Cone of Experience theory of Dale (1946), which states that hands-on, experiential learning is more effective than abstract methods. Furthermore, the principles of vocational education emphasize the concrete skills that students must master to prepare them for the world of work. Therefore, the need for practice-based learning media is urgent in the context of engineering education.

2. Design

This stage focuses on the design of the pyrolysis apparatus and the development of interactive learning e-modules. The pyrolysis apparatus design was created using SolidWorks 2020 software, then converted into working drawings for the manufacturing process. This apparatus is designed to enable students to understand the pyrolysis process flow, from heating the plastic, condensation, to the formation of pyrolysis oil. The Pyrolysis Design display can be seen in Figure 2.

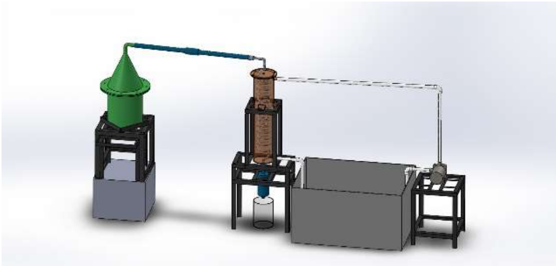

Figure 2. Pyrolysis Equipment Design

Meanwhile, the e-module is structured systematically, covering basic pyrolysis theory, equipment components, operating parameters, and applications of pyrolysis products. It also features Problem-Based Learning (PBL) questions and can be accessed as a flipbook via a link or QR code. In its development, this module adheres to the principles of systematic, comprehensive learning design that supports student independent learning. The e-module was designed using Canva as the primary platform, then converted into a flipbook using Heyzine to enhance student accessibility and engagement.

3. Development

The resulting design was then developed into a concrete prototype, either a device or a digital module. This stage involved fabricating the pyrolysis device using affordable and educational materials. The device's components include a heat-resistant steel reactor, an electric heater, a spiral tube condenser, and a liquid reservoir. The assembled pyrolysis device can be seen in Figure 3.

Figure 3. Pyrolysis Equipment

The compiled e-module was then converted into a flipbook using the Heyzine platform. The e-module cover can be seen in Figure 4.

Figure 4. Pyrolysis Learning E-Module

After the prototype was completed, validation was carried out by experts. Two material experts and two media experts assessed the suitability of the content, visual appearance, readability, completeness of the tools, and the suitability of the experimental procedures.

Table 1. Expert Validation Percentage Score

Validation Type	**Score Percentage (%)**	**Category**
Subject Matter Expert	95%	Very Eligible
Media Expert	81.76%	Very Eligible

The validators provided positive feedback, stating that this media can bridge the gap between concept and practice. Validation results indicate that the media meets the content and technical feasibility requirements and is ready for implementation.

4. Implementation

The implementation was conducted through a trial on 13 Mechanical Engineering Education students from the Faculty of Teacher Training and Education, Universitas Sebelas Maret, class of 2023, who had never taken a New and Renewable Energy course. The trial was conducted in two sessions. The first session consisted of completing a pretest and exploring the e-module. In the second session, students conducted a hands-on experiment using the developed pyrolysis apparatus.

Students participated in a practicum based on the worksheet included in the e-module, which systematically covered the pyrolysis oil production procedure. After completing the practicum, they completed a post-test and a user trial questionnaire. Data from the questionnaire were used to select three students as in-depth interview respondents, using a purposive sampling method based on high, medium, and low questionnaire scores.

Throughout the event, students appeared enthusiastic and actively engaged in discussions. They were directly involved in the experiments and showed interest in the process of converting waste to energy. The lecturer stated that learning became livelier because students not only received material but also experienced the process firsthand.

5. Evaluation

The evaluation was conducted using three instruments: pretest-posttest, user questionnaire, and interviews. The pretest and posttest results are shown in Table 2.

Table 2. Pretest and Posttest Average

Test Type	**Average**
Pretest	61,54
Posttest	85,96

The test results were then analyzed using Hake's (1999) normalized gain (N-Gain) formula. The N-Gain score was 55%, which is considered moderate. The N-Gain results indicate that the pyrolysis learning media had a positive impact on improving student understanding, although there is still room for further development.

Students were asked to complete a media assessment questionnaire. The results of the user trial can be seen in Table 3.

Table 3. User Trial Percentage Results

Assessment Aspect	**Percentage (%)**	**Category**
Learning Media Quality	86	Very Adequate
Effectiveness	77,5	Adequate
User Satisfaction	80,3	Adequate
Total	**82,4**	**Very Adequate**

Interviews were conducted with three students with different score backgrounds (high, medium, low). The results:

a. Students stated that the media made it "easier for them to visualize and understand" the concept of pyrolysis.
b. The e-module was considered practical and helpful because it could be accessed repeatedly.
c. Students said they were "more confident" in explaining the pyrolysis process to their peers

because they had already practiced it themselves.

The developed pyrolysis learning media have been declared feasible and effective in supporting New and Renewable Energy Learning. However, this research still has several limitations. The pyrolysis equipment used is simple and not equipped with a sensor-based measurement system, so monitoring of process parameters such as temperature and reaction time is still done manually. Furthermore, the scale of the equipment used is still limited to basic learning needs, so it does not fully represent an industrial-scale pyrolysis system. During the implementation stage, obstacles also emerged, such as limited time for practicums, the number of students who can use the equipment simultaneously, and differences in students' initial levels of understanding that affect the effectiveness of the learning implementation.

This pyrolysis learning media has the potential for further development to make it more relevant to the needs of engineering and vocational learning. Further development can be directed at adding digital sensor features to monitor pyrolysis process parameters in real-time, thus making learning more data-driven and supporting deeper conceptual understanding. Furthermore, the interactive e-module can be integrated with a Learning Management System (LMS) to support online and blended learning, as well as to facilitate lecturers in systematically monitoring student activities and learning outcomes. This development is expected to improve the quality of New and Renewable Energy learning and expand the use of media in engineering education.

CONCLUSIONS AND SUGGESTIONS

CONCLUSIONS

This study aims to design and develop pyrolysis learning media consisting of simple practical tools and interactive e-modules as part of an effort to improve the quality of learning in the New and Renewable Energy course. Based on the validation results carried out by experts, both material experts and media experts, it was found that the developed learning media met the feasibility standards as a teaching tool. Validation by material experts showed a feasibility level of 95%, while validation by media experts obtained a score of 81.76%. These results indicate that the pyrolysis learning media is suitable for use in learning activities.

In addition to feasibility, the effectiveness of the learning media was also measured through student trials. The results of the pretest and posttest showed a 55% increase in learning outcomes, which is considered a moderate improvement based on the normalized gain calculation. This finding indicates that the developed learning media is not only feasible to use but also significantly contributes to improving students' understanding of pyrolysis material, which was previously taught primarily theoretically.

Based on the results of user trials, the pyrolysis learning media obtained a feasibility score of 82.4%, indicating that the media is very suitable for use from a student perspective. In addition to quantitative data, the results of in-depth interviews with students also support the effectiveness of the media, where students stated that the use of practical tools and interactive e-modules facilitated a more applicable understanding of the pyrolysis process, increased self-confidence in practical activities, and fostered interest in learning about renewable energy. Thus, the developed learning media is relevant in supporting New and Renewable Energy learning and contributes to the development of practice-based learning in the field of engineering education.

SUGGESTIONS

Based on the findings and conclusions of this study, several suggestions can be put forward for further development, both in terms of practical implementation in the field and further academic development. These suggestions are organized in narrative form to make them easier to understand and implement by various stakeholders.

1. Widespread Institutional Implementation of the Media. It is highly recommended that the developed pyrolysis learning media be officially implemented immediately in the Mechanical Engineering Education Study Program and other engineering study programs. This will ensure that the media's benefits are widely felt by students and support more effective, practice-based learning.
2. Optimizing Media Use Through Active Strategies. The use of pyrolysis tools and e-modules needs to be optimized by implementing active learning strategies such as Problem-Based Learning (PBL) or Project-Based Learning (PjBL). These strategies can increase student engagement, strengthen conceptual understanding, and foster problem-solving skills that are highly relevant in the context of engineering education.
3. Media Expansion for Related Courses. This media is not only relevant for New and Renewable Energy courses, but also has the potential to be used to support learning in other courses such as Energy Conversion, Thermodynamics, or Waste Management Engineering. Therefore, lecturers and institutions are advised to consider using it across courses to increase the efficiency and relevance of learning.
4. Developing Similar Media for Other Topics. The success of this media development can serve as a basis for developing similar learning media for other abstract topics or those requiring hands-on practice, such as solar energy, wind turbines, or cooling systems. The development of e-modules and other practical tools will enrich the engineering learning approach, making it applicable and relevant to the needs of the times.
5. Further Research on a Broader Scale. To ensure the consistent effectiveness of this media, further research is needed involving a wider range of subjects, such as students from different classes, other engineering study programs, or even across institutions. Additionally, a quasi-experimental approach with control and treatment groups can be used to more deeply test the media's influence on learning outcomes.

6. Media Integration with Digital Learning Technology. E-modules already in flipbook format can be further developed within Learning Management Systems (LMS) platforms such as Moodle, Google Classroom, or individual campus platforms. This allows for digital tracking of student learning progress and encourages technology-based, independent learning.
7. Enhanced E-Module Features and Practical Tools. To enhance the quality of the media, the development of additional features such as interactive videos, pyrolysis process animations, or 3D digital simulations could be considered. Similarly, for practical tools, automatic temperature measurement features or pyrolysis yield sensors could be added to be more relevant to Industry 4.0 trends and the technological revolution in education.

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